

**\*\*FULL TITLE\*\***

*ASP Conference Series*, Vol. **\*\*VOLUME\*\***, **\*\*YEAR OF PUBLICATION\*\***

**\*\*NAMES OF EDITORS\*\***

## RS Ophiuchi in Quiescence: Why is it X-ray Faint?

Koji Mukai

*CRESST and X-ray Astrophysics Laboratory NASA/GSFC, Greenbelt,  
MD 20771*

*and Department of Physics, University of Maryland, Baltimore County,  
1000 Hilltop Circle, Baltimore, MD 21250*

**Abstract.** The short interval between successive outbursts of RS Oph strongly suggests that it has a high mass white dwarf accreting at a high rate. This, in turn, suggests the possibility of prominent X-ray emission from RS Oph in quiescence. However, archival quiescent X-ray observations of RS Oph show it to be a modest soft X-ray source but not a strong 2–10 keV X-ray source. In this aspect, RS Oph differs markedly from T CrB. We speculate on the possible mechanisms that could significantly suppress the 2–10 keV X-ray emission in RS Oph.

### 1. Motivation

The 2006 outburst of RS Oph is almost certainly due to a thermonuclear runaway of hydrogen rich fuel that has accumulated since the previous outburst in 1985. According to the theories of nova outbursts, both the white dwarf mass and the mass accretion rate must be high for two consecutive nova outbursts to be separated by such a short interval. According to the calculations of Yaron et al. (2005), a  $1.25 M_{\odot}$  white dwarf accreting at  $\sim 10^{-7} M_{\odot} \text{ yr}^{-1}$  would accumulate a sufficient amount of fuel in 20 years. This corresponds to a boundary layer luminosity of  $\sim 1.4 \times 10^{36} \text{ ergs s}^{-1}$ , assuming that half the potential energy is radiated away in the accretion disk and the white dwarf is rotating slowly. If RS Oph harbors a  $1.4 M_{\odot}$  white dwarf, it requires less fuel to achieve a thermonuclear runaway. Even then, an accretion rate of  $\sim 10^{-8} M_{\odot} \text{ yr}^{-1}$  is required, implying a boundary layer luminosity of  $\sim 3 \times 10^{35} \text{ ergs s}^{-1}$ . The boundary layer emission is likely to be in the hard or soft X-rays (Patterson & Raymond 1985a,b), where the contribution from the red giant mass donor is expected to be minimal.

### 2. Quiescent X-ray Observations

We have therefore searched the HEASARC archive for past, pointed X-ray observations of RS Oph, excluding those that were performed during the 1985 and 2006 outbursts, and found 7 observations using 4 satellites. These quiescent X-ray observations are summarized in Table 1. In calculating the luminosity, the distance to RS Oph was assumed to be 1.44 kpc, and no correction was made for absorption.

RS Oph was observed twice with *Einstein* IPC well before the 1985 outburst, and was undetected both times. The exposure times were 1.7 ksec in 1979 Sep

Table 1. Quiescent X-ray Observations of RS Oph

Date	Satellite	Sequence	Energy Range (keV)	Count Rate (ct s <sup>-1</sup> )	Luminosity (erg s <sup>-1</sup> )
1979-09-25	<i>Einstein</i>	I03190	0.2–3.5	$< 6 \times 10^{-3}$	$< 3.4 \times 10^{31}$
1981-04-03	<i>Einstein</i>	I10703	0.2–3.5	$< 2 \times 10^{-3}$	$< 1.1 \times 10^{31}$
1991-03-02	<i>ROSAT</i>	RP300038A00	0.2–2.4	0.0035	$9.4 \times 10^{30}$
1992-03-04	<i>ROSAT</i>	RP300038A01	0.2–2.4	0.0116	$3.1 \times 10^{31}$
1997-02-04	<i>RXTE</i>	20027-01-01-00	2–10	0.16	$2.4 \times 10^{32}$
1997-02-06	<i>RXTE</i>	20027-01-01-01	2–10	0.10	$1.7 \times 10^{32}$
1997-03-13	<i>ASCA</i>	35003000	0.7–2.0	$1.3 \times 10^{-3}$	$8.6 \times 10^{30}$
			2–10	$1.2 \times 10^{-3}$	$\leq 5 \times 10^{31}$

and 5.5 ksec in 1981 Apr. In Table 1, we give approximate upper limits, based on an estimate that 10 source counts would have resulted in a detection. The luminosity limits are then inferred assuming the plasma model parameters that fit the *ROSAT* data described below.

The *ROSAT* PSPC detections have already been published by Orio (1993) and by Orio et al. (2001). The former reported on the first observation, and the latter was a compilation of a large number of *ROSAT* observations of novae and recurrent novae. In Figure 1 (left), we show the PSPC spectrum from the second *ROSAT* observation, together with a *mekal* model fit, from which we obtain a plasma temperature of  $kT \sim 0.6$  keV and an absorbing column of  $N_H \sim 9.6 \times 10^{21}$  cm<sup>-2</sup>. Note, however, that the fit is neither unique nor well constrained due to the low statistical quality of the data. The estimated  $N_H$  value suggests that the intrinsic (unabsorbed) luminosity is about 10 times higher than the observed (absorbed) value. While these *ROSAT* observations do establish RS Oph as a soft X-ray source, what about the 2–10 keV band?

The two *RXTE* observations should be considered non-detections, even though the observed count rates are higher than the predictions of the background model. The count rate excesses are statistically significant, and are above the estimated systematic errors of the background model that reproduces the non X-ray background and the average cosmic X-ray background. However, give the location of RS Oph and the collimator response of *RXTE* PCA, contamination due to Galactic X-ray background and faint, discrete sources in the field of view at the observed level is quite possible. Imaging X-ray telescopes are necessary to securely detect RS Oph in quiescence.

The *ASCA* observation with an exposure time of  $\sim 34$  ksec is the most sensitive observation to date of 2–10 keV emission from RS Oph in quiescence. Of the two types of detectors on-board *ASCA*, SIS is more sensitive below 2 keV, while GIS is more sensitive for harder emission. The values tabulated in Table 1 are from GIS in two energy bands. While RS Oph is securely detected below 2 keV ( $1.3 \pm 0.4 \times 10^{-3}$  ct s<sup>-1</sup>), it is not so in the 2–10 keV band ( $1.2 \pm 0.8 \times 10^{-3}$  ct s<sup>-1</sup>). The analysis of SIS data produces similar results.

Due to the marginal statistical quality of the data, spectral fitting cannot provide tight constraints on the spectral shape. However, the same  $kT \sim 0.6$

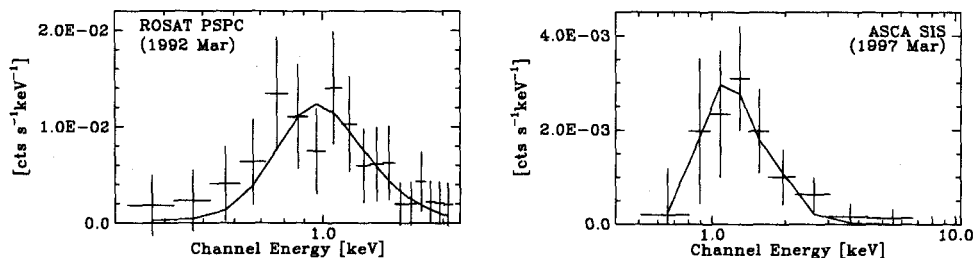


Figure 1. (Left) The *ROSAT* PSPC spectrum of RS Oph from the 1992 Mar observation. Data and the best-fit mekal model are shown. (Right) ASCA SIS spectrum of RS Oph, shown with the  $kT=0.6$  keV mekal model.

keV plasma model that was used for the *ROSAT* spectrum provides a good description of the data below 2 keV, resulting in a luminosity compatible with the first *ROSAT* observation. This model is shown with the SIS data in Figure 2 (right). The possible excess of data over this model above 2 keV may indicate that the emitting plasma is hotter than 0.6 keV overall, or that there is an additional contribution from a hotter plasma.

This is very different from the highly absorbed, bright X-ray component seen in the quiescent recurrent nova, T CrB (Luna et al. 2007), which is otherwise very similar to RS Oph. T CrB has a very hard, highly absorbed X-ray emission with little flux below 2 keV, with an observed 2–10 keV luminosity of  $1\text{--}2 \times 10^{33}$  ergs s $^{-1}$ . A 2–10 keV GIS count rate of  $1.2 \times 10^{-3}$  cts s $^{-1}$  corresponds to an absorbed luminosity of  $2\text{--}5 \times 10^{31}$  ergs s $^{-1}$  for a  $kT=30$  keV Bremsstrahlung spectrum absorbed with  $N_H$  of  $10^{22}\text{--}10^{24}$  cm $^{-2}$ . The unabsorbed luminosity may be up to a factor of 10 higher for the extreme absorption case.

### 3. Discussion

Compared with the expected accretion luminosity from the boundary layer, both the observed soft X-ray luminosity and the undetected hard X-ray luminosity of RS Oph are extremely low. Thus, we have a case of “missing boundary layer” problem in RS Oph that is perhaps more extreme than any seen in non-magnetic cataclysmic variables (CVs; van Teeseling et al. 1996). In fact, we may not have detected any boundary layer emission from RS Oph at all: the properties of the detected soft emission is quite similar to those seen in several other symbiotic systems (Mürset et al. 1997), for which a colliding winds interpretation has been put forth.

It is unlikely that absorption alone can extinguish the hard X-ray flux sufficiently. The above analysis shows that even an extreme  $N_H$  of  $10^{24}$  cm $^{-2}$  is insufficient in itself to reduce a 2–10 keV X-ray component at the T CrB level to below ASCA detectability level. Moreover, such a high column density is significantly above those seen in the hard X-ray component of T CrB, the X-rays from RS Oph in outburst (up to  $5 \times 10^{22}$  cm $^{-2}$  for the early shock emission; Sokoloski et al. 2006; Bode et al. 2006), or in optical data for RS Oph in quiescence ( $\sim 10^{23}$  cm $^{-2}$ ; Anupama & Mikołajewska 1999).

If the boundary layer is completely optically thick, hard X-rays will not result. Note that the resulting soft X-ray component is likely to be hot in this case. For example, a  $1.4 M_{\odot}$  white dwarf accreting at  $\sim 10^{-8} M_{\odot} \text{ yr}^{-1}$  over 10% of its surface area should emit a  $kT \sim 50$  eV blackbody-like soft component, which can only be hidden by a high, though realistic, intrinsic column. In any case, the lack of a hard component is puzzling since, empirically speaking, the boundary layer always appear to have a surface layer optically thin enough to produce hard X-rays (Patterson & Raymond 1985a).

If the white dwarf in RS Oph is spinning rapidly, near the break-up frequency, while that in T CrB is not, this would explain the low boundary layer luminosity in the former. While UV spectroscopy of non-magnetic CVs show that they harbor slowly rotating white dwarfs (Sion 1999), accretion of a few tenths of a solar mass should be enough to spin up the CV primaries to near break-up. CV primaries are slow rotators probably because of the angular momentum removed during nova outbursts, which eject more mass than accreted (King et al. 1991) and have an extended common envelope phase (Livio & Pringle 1998). Neither is thought to be the case with RS Oph. The high white dwarf mass inferred for RS Oph almost certainly means that it has accreted a significant amount of mass, and therefore angular momentum. If indeed the nova mechanism is ineffective in removing angular momentum from the white dwarf in RS Oph, it is quite possibly a fast rotator.

However attractive this possibility may be, it remains a pure conjecture. Independent studies of this using, e.g., the morphology of the ejecta (O'Brien et al. 2006), as well as future quiescent X-ray observations, are strongly encouraged.

**Acknowledgments.** This research has made use of data obtained from the High Energy Astrophysics Science Archive Research Center (HEASARC), provided by NASA's Goddard Space Flight Center.

## References

- Anupama, G.C. & Mikołajewska, J. 1999, *A&A*, 344, 177  
 Bode, M.F., O'Brien, T.J., Osborne, J.P., Page, K.L., Senziani, F., Skinner, G.K., Starrfield, S., Ness, J.-U., Drake, J.J., Schwarz, G., Beardmore, A.P., Darnley, M.J., Eyres, S.P.S., Evans, A., Gehrels, N., Goad, M.R., Jean, P., Krautter, J., Novara, G. 2006, *ApJ*, 652, 629  
 King, A.R., Wynn, G.A. & Regev, O. 1991, *MNRAS*, 251, 30P  
 Livio, M. & Pringle, J.E. 1998, *ApJ*, 505, 339  
 Luna, G.J.M., Sokoloski, J.L. & Mukai, K., 2007, in preparation.  
 Mürset, U., Wolff, B. & Jordan, S. 1997, *A&A*, 319, 201  
 O'Brien, T.J., Bode, M.F., Porcas, R.W., Muxlow, T.W.B., Eyres, S.P.S., Beswick, R.J., Garrington, S.T., Davis, R.J. & Evans, A. 2006, *Nature*, 442, 279  
 Orio, M. 1993, *A&A*, 274, L41.  
 Orio, M., Covington, J. & Ögelman, H. 2001, *A&A*, 373, 542  
 Patterson, J. & Raymond, J.C. 1985, *ApJ*, 292, 535  
 Patterson, J. & Raymond, J.C. 1985, *ApJ*, 292, 550  
 Sion, E.M. 1999, *PASP*, 111, 532  
 Sokoloski, J.L., Luna, G.J.M., Mukai, K. & Kenyon, S.J. 2006, *Nature*, 442, 276  
 van Teeseling, A., Beuermann, K. & Verbunt, F. 1996, *A&A*, 315, 467  
 Yaron, O., Priyalnik, D., Shara, M.M. & Kovetz, A. 2005, *ApJ*, 623, 398